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"GRADES OF STEEL"

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“GRADES OF STEEL”

By H. P. PARROCK, S. B.

To L. B.

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INTRODUCTORY

This booklet aims to instruct the machinist and the tool maker, the final users of tool steel—the men upon whom the ultimate economies depend. The object in giving the various open hearth analyses is to indicate the careful selection that is made for various purposes and to show the grades that lead up to the crucible steels.

Economy in steel is becoming more and more necessary, and probably no commodity of so much importance has been so grossly wasted. If it pays to select grades at $30.00 per ton it surely pays to choose carefully at $3000.00 per ton, however relatively small the more expensive item may be.

The author believes that the care in manufacture that this booklet merely indicates will help the machinist and tool maker toward an attitude of economy in the use of steel that will be of value to them individually, and to men higher up.

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The author wishes to acknowledge the use of data from "On the Art of Cutting Metals," by F. W. Taylor and from the catalog of The Shore Instrument & Mfg. Co. The courtesy and kindness of Mr. Taylor and Mr. Shore is appreciated.

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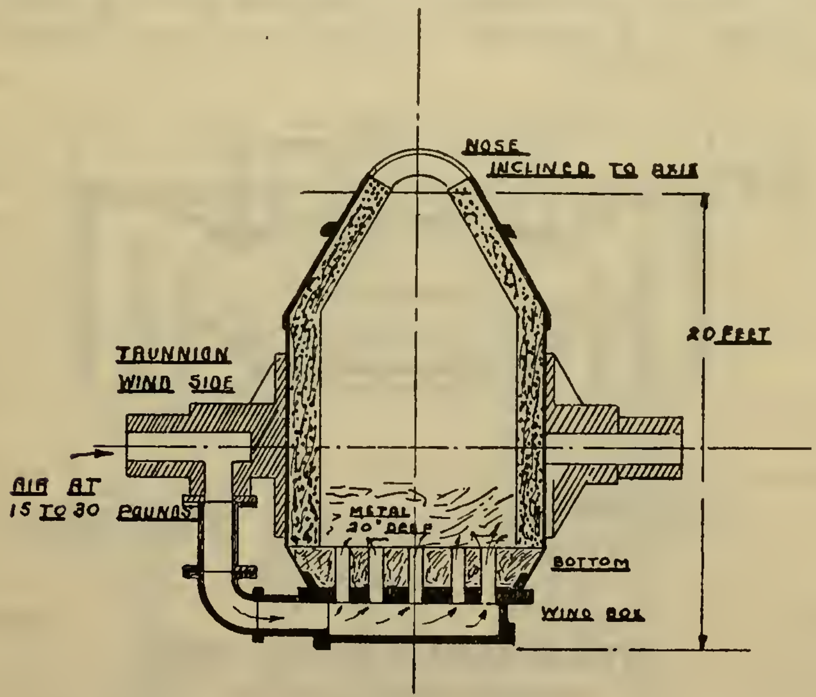
METHODS OF MANUFACTURE

Steel is, in general, made by one of the following processes:

"**Bessemer**" —in which air, usually in its natural condition, is blown through molten pig metal until (in the acid process) the manganese, silicon and carbon are practically burned out. Silicon, oxidizing to SiO_2, furnishes most of the heat for the process. The "blow" is continued until a metal hot enough to handle in ladles is obtained, when the product is poured as steel, various additions of ferromanganese, spiegel, or other metalloids, or carbon being made, in the ladle, to give the whole the desired chemical and physical properties. In the United States, all Bessemer converters are "acid."

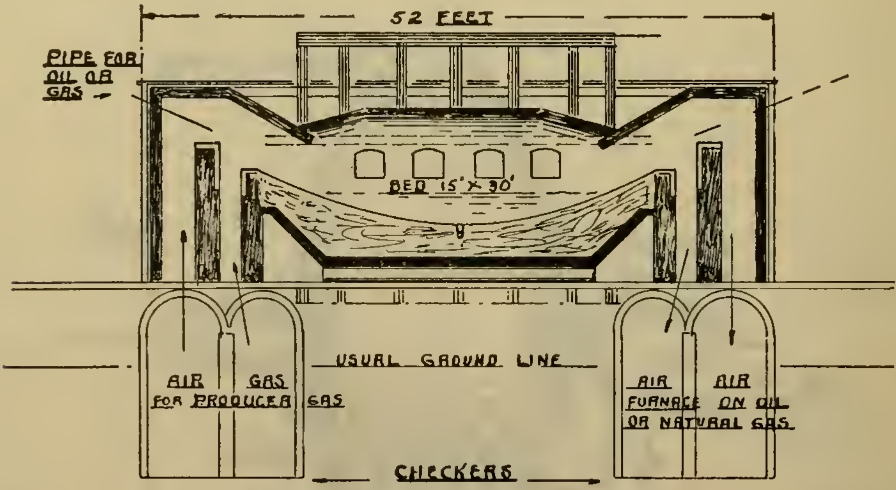


CUT 1 (PARROCK)

BESSEMER CONVERTER

Cross section through trumnions; capacity about 15 tons per heat; 3 to 5 heats per hour. Bessemer Converters are installed usually in batteries of two, often of three or four.

"Open Hearth"—in which pig iron, or steel, or both, cold or molten, with iron ore, are melted in a furnace suitably built of refactory materials, by the action of a flame produced by coal gas or oil or natural gas. The heat for the process is derived mainly from the flame supplied. The process is continued until at the right temperature for pouring, the approximate chemical and physical conditions will result in the finished material, additions of ferromanganese, ferro-phosphorus, or other metalloids, or carbon being made, generally as the heat goes into the ladle. Lime is included with raw materials when the hearth or bottom of the furnace is made of dolomite, lime, or magnesite, the furnace and its product being designated as "basic"; steel made on a hearth of sand, and the furnace as well, is known as "acid." The use of regenerating chambers (checkers) and reversing valves for the fuel and air is demanded by the nature of the process and the intense heat desired.



CUT 2 (PARROCK)

OPEN HEARTH FURNACE—(Basic)

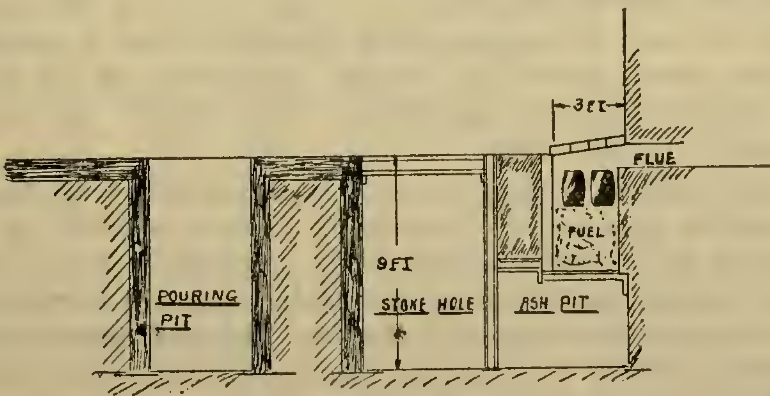
Capacity 52 tons per heat.

Arranged to use oil or natural gas, the arch being omitted over the gas "up take." Oil or natural gas is piped as indicated; producer gas, when used, enters through "gas" chambers. All waste gases pass out through both chambers. Open hearth furnaces are installed usually in groups of 10 to 12, to form one unit.

"**Duplex**"—in which metal from which silicon has been blown, or burned out, in the Bessemer process, is transferred while molten to an Open Hearth furnace, usually "basic." This process was invented to overcome the disadvantage of ores high in phosphorus, sulphur and silicon, when it was desired to convert such ores into steel.

"**Transfer**"—in which steel sufficiently cleansed of phosphorus and sulphur, in a "basic" open hearth furnace, is transferred in a ladle, to an "acid" open hearth furnace where the metal is handled as an "acid" heat, and so accepted when finished and inspected. The "Duplex" and "Transfer" processes are modifications or combinations of "Bessemer" and "Open Hearth."

"**Crucible**"—in which steel or iron, or both, generally in various stages of previous refinement, with charcoal, or tungsten, or chrome or vanadium or other "alloys," or any of them, are melted in a crucible of clay, or graphite. The crucibles are covered, enclosing the metal, and are placed in the path of a flame produced by coal, oil, or gas, or directly on a bed of fuel, preferably coke or anthracite. The metals derive heat through the walls of the crucible; the flame does not come in contact with the metal. Heat is applied to the crucible until, passing through various stages, the metal attains the proper temperature and condition for pouring.



CUT 3 (PARROCK)

CRUCIBLE PITS

Capacity 100 pounds per pot.

The fuel in this case is anthracite coal.

Bessemer converters are generally of 10 to 20 tons capacity; a heat is blown in 8 to 20 minutes; the depth of metal in the bath varies from 12″ to 26″.

Open hearth furnaces vary in capacity from 5 to 250 tons, depending upon the requirements and some modifications of the process. The usual capacity is 50 to 60 tons, the depth of the bath 18″ to 24″. The time required to melt a heat is 5½ to 12 hours, depending upon the mixture, the construction of the furnace, the fuel, the melter and the product desired.

Crucible pots generally hold 100 to 125 pounds of material. The time required in melting, killing, pulling and pouring runs from 2½ to 5 hours.

Bessemer steel is in demand for rails, sheet bars, pipe, structural shapes, bars, bolts, nut and screw steel and the cheaper forms of steel products. Bessemer steel replaced commercial iron and is in turn being succeeded by open hearth steel. Open hearth steel is used for structural shapes, rails, sheet bars, forgings, rivets, springs, axles, nuts, bolts, screws, castings, and bars for all purposes to which steel is put. It is used to make cutting tools of the cheaper forms, and frequently for remelting purposes by makers of crucible steels.

Crucible steel is demanded for cutting tools, dies, fine springs and all the more expensive articles for which steel is available. Important levers, piston rods, shafts, gears, files of the better grade, hammers, surgical instruments, cutlery, knives, razors, etc., are made of crucible steels.

Rapid advance is being made in the manufacture of steel by the electrical process; one furnace of 15 tons capacity, in this country, is said to have turned out 17 heats in 24 hours. This furnace receives partly converted metal, continuing the purification, much as in the "Duplex" process. The possibilities of electric melting are far reaching and the development of the process is being watched by all metallurgists.

VARIOUS GRADES OF STEEL

In order to indicate the variety of steels specified and used for various purposes, and show the relation between open hearth and crucible steels, so far as analyses go, the following data is offered. The open hearth analyses are taken from personal notebooks and the comments are based on observation. Bessemer steel analyses are not offered, since in all cases, open hearth steels are made to replace them, and further since they do not greatly interest users of tool steels. All of the following analyses are of open hearth steels, "basic" or "acid" as indicated; the crucible analyses when given later, are designated "crucible."

The following abbreviations are used throughout:

T. S. Tensile strength, in pounds per square inch.
E. L. Elastic limit, in pounds per square inch.
E. R. Elastic ratio, %.
El. Elongation, % in 8".
R. A. Reduction of Area, %
C. Carbon %.
Mn. Manganese %.
P. Phosphorus %.
S. Sulphur %.
Si. Silicon %.
Cu. Copper %.
Mo. Molybdenum %.
Va. Vanadium %.
W. Tungsten %.
Cr. Chromium %.

Table (1) DEAD SOFT BASIC

T.S.	C.	Mn.	P.	S.	Si.	E.R.	El.	R.A.
44710	.04	.15	.008	.030	Low	57	28	50
45230	.05	.12	.008	.024	"	To	To	To
44930	.06	.12	.011	.025	"	64	30	58
45390	.035	.10	.008	.022	"			
45520	.04	.14	.007	.020	"			

For—Soft rivets, wire, seamless drawn tubing, lap-weld pipe, chain, cold drawing, stamping and pressing, soft machinery bars and stay bolts; flanging plate, boiler plate, etc. (Table (2) shows a better steel for seamless drawn tubing. Soft steels work best at a very high rolling or forging heat. Heat thoroughly and very hot. These steels take the maximum amount of draft but show a tendency to minute surface seams. They should be "chipped" carefully in the billet when used to make stamping plate).

Table (2) SOFT BASIC

T.S.	C.	Mn.	P.	S.	Si	E.R.	El.	R.A.
49150	.09	.35	.007	.030	Low	58	28	50
49080	.09	.43	.008	.032	"	To	To	To
50350	.09	.48	.011	.025	"	64	30	58
49230	.09	.39	.008	.032	"			
50920	.10	.45	.020	.031	"			

For—Bridge and ship rivets, seamless drawn tubing, lap weld pipe, cold stamping, pressing, flanging, drawing, stay bolts, ties, boiler plate, chain, metal wheels, wagon tires, crane bridges, etc. For soft bars and special structural shapes, where great strength is not required. (Copper should be kept below .20% in steels subject to very hot working, as in drawing seamless tubing. Copper is generally conceded to have little action on the physical properties of cold steel, and is in general, disregarded. It does have a bad effect in hot-working all open hearth steels when present up to .60% accompanied by high sulphur and in seamless drawn tubing when present up to .30%. It shows up in the first drawing).

Table (3) TUBING
"Basic"

T.S.	C.	Mn.	P.	S.	Si	E.R.	El.	R.A.
51200	.11	.41	.007	.022	Low	58	28	50
51080	.095	.54	.007	.026	"	To	To	To
51370	.11	.48	.009	.031	"	64	30	58
50350	.09	.48	.011	.025	"			
51950	.085	.46	.012	.024	"			

For—Seamless drawn tubing, lap-weld pipe, boiler, bridge and ship rivets, chain, wagon tire, soft machinery bars, cold drawing and stamping, wire, stay-bolts, ties, etc. A stiffer steel than Soft Basic. Suitable for structural shapes not requiring great stiffness. A good steel to subject to shock, as in cranes, presses, etc. For boiler and tank plate; very easily flanged.

Table (4) TIN BAR

"Basic"

T.S.	C.	Mn.	P.	S.	Si.	E.R.	El.	R.A.
	.13	.44	.076	.034	Low			
	.10	.45	.089	.034	"			
	.10	.43	.074	.043	"			
	.10	.44	.080	.036	"			
	.12	.42	.088	.029	"			

The high phosphorus prevents "sticking" during the process of making sheets. The phosphorus is added as ferro-phosphorus as the heat goes into the ladle. This is generally considered a special steel. It is suitable for bolts, line pipe, etc. ("Low" Silicon means from a trace to .03%).

Table (5) RIVET

"Basic"

T.S.	C.	Mn.	P.	S.	Si. Under	E.R.	El.	R.A.
54470	.15	.36	.007	.035	.05	58	28	50
53020	.12	.45	.007	.024	"	To	To	To
52520	.12	.42	.010	.031	"	64	30	58
53780	.14	.52	.007	.027	"			
55670	.14	.46	.007	.030	"			

For—Bridge and ship rivets, seamless drawn tubing, expanded metal, pipe skelp, structural shapes for small work, nuts, bolts tank plates, boiler plate, etc., fire box plate. (For any grade of rivet steel the largest size rivet is best made of the softest steel, within the allowable range. That is, make 1¼" rivets from bars of the 3rd heat; ½" of the 5th heat).

Table (6) NUT AND SCREW STEEL

"Basic"

T.S.	C.	Mn.	P.	S.	E.R.	El.	R.A.	
55000	.12	.68	.012	.124	54	25	45	Nut
	.14	.65	.030	.132	To	To	To	"
To	.18	.62	.060	.072	60	30	55	Bolts
	.17	.69	.066	.065				"
70000	.21	.62	.058	.078				Screws

The high phosphorus and sulphur facilitate threading, due to the easy snapping of the particles before the dies. The tendency of the soft steel to curl and choke the dies is reduced to a minimum. This steel should be worked either very hot or very cold; preferably very hot for ease in rolling. These are the grades for the commercial nut or bolt steel. Any of the preceeding steels, except "Tin Bar" would be suitable for braces, nuts, heavy bolts, tie rods, etc., where ease of threading would have to be sacrificed to safety. These are special steels, designed to help the machinist. Phosphorus is kept low for a certain class of bolts where ability to resist shock is important.

Table (7) RIVET

"Basic"

T.S.	C.	Mn.	P.	S.	Si. Under	E.R.	El.	R.A.
60830	.19	.50	.007	.028	.05	54	25	45
62340	.20	.48	.014	.029	"	To	To	To
59970	.17	.57	.007	.032	"	60	30	55
59920	.19	.56	.007	.031	"			
61740	.18	.56	.007	.030	"			

For—Bridge and ship rivets of high grade, where stiffness is wanted. For bars, nuts, bolts, wire, shafting, spikes, tank plates, splice bars, tie plate. For structural shapes for cranes, bridges and machinery exposed to shock. This is a good 58-62000 T. S. specification for bridge shapes, cable wire, etc. A very good steel for all structural work. For: flanging, and boiler plate.

Table (8) STRUCTURAL

"Basic"

T.S.	C.	Mn.	P.	S.	Si. Under	E.R.	El.	R.A.
64060	.23	.52	.012	.031	.05	50	23	45
64112	.23	.57	.007	.036	"	To	To	To
65100	.22	.61	.010	.029	"	60	29	55
65460	.24	.57	.008	.034	"			
66080	.22	.61	.010	.029	"			

For—Bridges, structural shapes of all kinds, machinery steel, very soft forgings, hammer work, tank plates, drop forgings, boiler plate, tie plate, splice bars, bars for reinforcing concrete, etc. (This grade corresponds to a .10%-.13% carbon acid bessemer in tensile strength. Most of the commercial bars in service are rolled from this grade or those slightly softer. This table is typical of 60-70,000 T. S. basic open hearth steel and is suitable for rigid constructions with a factor of safety of 4 to 6. This is the upper limit for ordinary boiler plate).

Table (9) HARD STRUCTURAL

"Basic"

T.S.	C.	Mn.	P.	S.	Si. Under	E.R.	El.	R.A.
74560	.34	.38	.007	.026	.05	50	20	35
70430	.28	.40	.025	.055	"	To	To	To
72650	.34	.55	.013	.055	"	60	30	45
69480	.28	.42	.008	.037	"			
72010	.27	.64	.015	.045	"			

For—Large bridges not subjected to heavy shocks.

For—Special structures requiring stiffness; shafting, beams, channels, bars for reinforcing concrete, stiff plate, etc. This grade represents the upper limit of tensile strength in structural work. This steel requires care in handling, especially in heating.

Table (10) SOFT FORGING

"Acid"

T.S.	C.	Mn.	P.	S.	Si.
56290	.13	.49	.035	.034	.10
58060	.16	.43	.042	.049	To
55740	.12	.41	.032	.048	.15
60180	.15	.43	.034	.050	
61370	.15	.47	.044	.054	

Elongation in 2" over 30.
Reduction of area over 35.

For—Soft forgings, solid or hollow, no thickness over 10". For structural shapes, ship angles, beams, channels, merchant bars, shafting, splice bars, tie plate, etc. (All forging steel needs careful heat treatment. Hammer work requires that the heat in a piece of steel be uniform throughout or bad shrinkage stresses will be set up. To offset these stresses, in part, annealing is resorted to; but annealing will not entirely remedy bad heating and working).

Table (11) FORGING

"Acid"

T.S.	C.	Mn.	P.	S.	Si.
71960	.25	.53	.026	.048	.11
68160	.25	.41	.029	.033	
69260	.25	.68	.036	.039	
72850	.25	.55	.045	.049	
72010	.27	.64	.015	.045	

Elongation in 2" over 24.
Reduction of area over 30.

For—Large forgings having over 18" thickness of section.

For—Stiff structural work, stiff wire for suspension work, reinforcing bars, drop-forgings for small stiff work; small engine forgings, tin mill screws and boxes, stiff tank plate.

Table (12) **MEDIUM FORGING**

"Acid"

T.S.	C.	Mn.	P.	S.	Si.
82780	.32	.46	.022	.036	.10
80220	.33	.60	.042	.047	
76040	.29	.49	.034	.048	.15
82780	.32	.46	.022	.036	.10
83820	.327	.58	.029	.037	.23

Elongation in 2" over 22.
Reduction of area over 30.

For—Solid and hollow forgings of thickness of metal of 12" and under; locomotive rods, axles, crank webs, link pins, piston rods, engine forgings, propeller shafts, etc.

For—Large forgings, light rails, cut gears, reinforcing bars, hot shear blades, etc., tin mill screws and boxes.

Table (13) **HARD FORGING**

"Acid"

T.S.	C.	Mn.	P.	S.	Si.
97320	.472	.53	.039	.047	.19
97610	.439	.53	.027	.051	.21
94230	.491	.54	.029	.045	.31
92610	.430	.48	.025	.043	.23
94480	.447	.44	.022	.040	.17

Elongation in 2" over 10.
Reduction of area over 45.

For—Oil tempered forgings up to 4" thickness. For engine forgings, locomotive tires, crank pins, webs, crank rods, piston pins and rods, and shear blades for hot work; heavy rails, cut gears, etc. For very heavy hot die work, drop forging dies, etc., tin mill screws, boxes.

Table (14) VERY HARD FORGING

"Acid"

T.S.	C.	Mn.	P.	S.	Si.
113580	.535	.59	.029	.048	.24
112550	.602	.49	.016	.040	.18
110580	.58	.53	.018	.040	.19
105700	.50	.53	.020	.031	.19
105680	.48	.52	.012	.028	.20

Elongation in 2" over 16.
Reduction of area over 45.

For—Oil tempering and very hard stiff forgings.

For—Freight locomotive tires, car wheels. For rough tools, very heavy rails, heavy hand tools, wearing surfaces subject to rough usage. For axles, cranks, steel tires, cut gears. This is a very high grade steel when well made, deserving good treatment.

(All forgings should be annealed to relieve internal stresses due to the hammer, for best service. ''Soft'' forging, however, as it is generally used for the less important work, is very often allowed to cool slowly without annealing).

Table (15) STEEL CASTINGS

"Acid"

C.	Mn.	P.	S.	Si.	
.27	.68	.066	.047	.261	Mach'ry, boxes, spindles, cranes, etc.
.25	.72	.057	.048	.261	'' '' '' '' ''
.28	.66	.043	.043	.30	'' '' '' '' ''
.45	.74	.040	.044	.295	Mill crabs, cut gears, etc.
.88	.74	.040	.050	.32	Rolls (Hot Rolling).
.87	.74	.039	.037	.30	'' '' ''
.84	.75	.042	.032	.295	'' and special levers
.95	.72	.035	.042	.28	'' '' '' castings.
1.05	.71	.040	.035	.32	Special, hard castings.

Elongation in 2" (medium) over 17.
Reduction of area over 24.
Heats 1-3 are medium hard.

Table (16) HIGH CARBON STEELS

"Basic"

C.	Mn.	P.	S.	Si.	
.656	.45	.027	.045		Special tempered forging.
.705	.27	.015	.038	.11	Crucible remelting, forgings.
.730	.22	.009	.047		Special tempered forgings, springs.
.759	.31	.028	.051	.15	" " " files.
.809	1.10	.016	.040		Tempered piston rod, engine valve stems.
.850	.27	.029	.041		Crucible remelting; special shafting.
.869	.50	.020	.046		Heavy springs, files.
.909	.45	.035	.031		Springs and tools, wearing surfaces.
.955	.23	.011	.052		" " " heavy die blocks.
.972	.26	.009	.036		" " " files.
1.000	.28	.011	.045		" " " cutting tools.
1.014	.24	.009	.036		Anvil faces, die blocks.
1.035	.24	.007	.039		Springs, die blocks, files.
1.074	.27	.012	.036		" tools.
1.121	.31	.030	.048		" wearing plates.
1.140	.32	.012	.051		Springs and tools, files.
1.145	.22	.007	.046		" " "
1.162	.29	.007	.038		" " "
1.175	.33	.007	.030		Special springs, files.
1.216	.33	.015	.040		" "
1.223	.23	.027	.044		Tools and springs, heavy wearing surfaces.
1.286	.30	.007	.049		Tools and springs.
1.415	.34	.046	.036		" " "

Table (17) SPECIAL STEELS

"Acid"

T.S.	C.	Mn.	P.	S	Si.	Cu.	Ni.	
89,960	.28	1.05	.042	.065				
86,420	.28	1.21	.063	.064				
	.30	1.20	.066	.060				
120,550	.395	1.34	.070	.060				
	.342	.76	.053	.035	.31	.45	3.43	"Nickel" forging.
	.32	.62	.050	.040	.27	.20	3.40	" "
	1.724	17.75						
	1.201	10.67						
	1.02	12.54						

The first three heats are well adapted for cotton mill spindles which must be light, stiff, and capable of a smooth finish. These steels are suitable for axles, or for shafting requiring a smooth finish. For polished levers, hand rods, etc. The 4th heat is a stiffer steel for the same purpose. Any of these 4 heats are suitable for axles for buggy work; they take a smooth finish. The nickel heats are typical of this grade of steel; an excellent specification for nickel forgings. The last three heats are manganese steels for wearing surfaces such as railway cross ores, switch points and for grinding surfaces, stamping shoes, crushers, etc. They are hard to machine, requiring special high speed steels.

Table (18)

CARBON STEELS

"Crucible"

(Tools for Cutting Purposes)

These steels harden in water.

Authority.	No.	C.	Mn.	P.	S.	Si.	Va.	Cr.	Welds with	Hardens at F°
P	1	.32	.60	.035	.019				ease	1600
Howe	2	.55			.260				"	1450
Taylor	3	.681	.198	.024	.011	.219			"	1450
P	4	.752	.215	.020	.027	.201			"	1425
P	5	.876	.25	.027	.030	.24			care	1425
Taylor	6	.992	.318	.037	.020	.256			"	1420
Taylor	7	1.047	.189	.017	.017	.206			"	1420
P	8	1.132	.202	.026	.015	.262	.08		great care	1410
Taylor	9	1.240	.156	.016	.006	.232		.079	great skill	1400
P	10	1.412		.021	.011					1395
P	11	1.542	.241			.276				1390
Shore	12	1.65								1385
Shore	13	1.75								1385

FOR

1. Rough chisels, mauls, sledges, heavy hand tools, hammers.
2. Stamping dies, boiler cups, chisels, hammers.
3. Stamping dies, boiler cups, chisels, and lathe and planer tools.
4. Stamping dies, boiler cups, chisels, and lathe and planer tools.
5. Stamping dies, boiler cups, chisels, and cold sets and hammers.
6. Stamping dies, boiler cups, chisels, and cold sets and hammers.
7. Lathe and Planer tools, cold chisels and hot sets.
8. Lathe and Planer tools, taps, screws, dies, etc.
9. Lathe and Planer tools, taps, screws, dies, etc.
10. Drills, saws, chilled roll tools, dies.
11. Drills, saws, chilled roll tools, dies, razors, etc.
12. Drills, saws, chilled roll tools, dies and for all very hard fine tools.
13. Drills, saws, chilled roll tools, dies and for all very hard fine tools.

Table (19) **CARBON ALLOYS**

"Crucible"

These steels harden in water and in oil.

	No.	C.	Mn.	P.	S.	Si.	W.	Cr.	Hardens at F°
Taylor	1	.710	.102	.016	.008	.326		1.773	1420
"	2	.745	.102	.016	.013	.287		1.631	1420
Shore	3	1.000						3.50	1400
Taylor	4	1.220	.300	.017	.010	.180	6.75		1395
"	5	1.376	.552			.255	1.842		1390

For—Lathe and planer tools, dies, drills, taps, cutters, saws and cutting tools. For special machinery, automobiles, etc. These are essentially tool steels. Steels of this kind, while carrying (W) and (Cr), or both, in small quantities, require the heat treatment of straight carbon steels. The alloys give increased strength and resistance to shock, but do not in these quantities, render the steel "self-hardening." Practice has shown that both (W) and (Cr) must be present in the proper quantities to make steels effective as a cutting medium at high temperatures—that is to make them "high speeds." (Mo) is sometimes used to replace (W).

Table (20) SPECIAL GEAR STEELS

Acid Open Hearth and Crucible.

No.	C.	Mn.	P.	S.	Si.	Ni.	Cr.	Va.
1	.425	.59	.012	.032	1.98			
2	.723	.61	.010	.024	1.95			
3	.249	.32	.007	.032	.28	2.95	1.24	
4	.112	.35	.007	.052	.18	3.47	.25	
5	.101	.29	.007	.024	.30	5.40	1.80	
6	.252	.40	.012	.030	.28	4.95	.92	.10
7	.31	.65	.007	.022	.19	3.20	1.50	
8	.52	.32	.012	.031	.22	2.95	.85	.06

These steels are suitable for very high grade cut gears, and machine parts that must be hard and very strong. Steel No. 7 would probably have an ultimate strength of 135,000 pounds per square inch, with an elastic limit of 125,000 pounds. These are very special steels suitable for the more expensive machinery, as automobiles, flying machines, etc. These steels require very special hardening and tempering. Some of them are capable of air hardening, as shown by a later table. The first two are known as ''silicon'' steels; the balance as ''chrome nickel'' steels. All of these steels harden in water; 4 and 5 are best used in the natural state for vibrating or twisting parts of machinery.

Nickel-chrome steels are best practice for heavily stressed members in bridge work, and a straight 3.50% nickel steel of about .35 carbon is also an excellent specification for very important work. Alloy steels, properly made, will take 10 to 12 times the number of twists that straight carbon steels will take in the flexure test. Their increased cost is more than offset by the resistance to shock, the decrease in weight of material necessary, and the great strength.

Table (21)

SELF HARDENING

"Crucible"

These steels harden in air or in oil.

	No.	C.	Mn.	P.	S.	Si.	W.	Cr.
Taylor	1	1.143	.18	.023	.008	.246	7.723	1.830
"	2	1.842	2.43	.023	.007	.890	11.59	2,694
"	3	2.150	1.578			1.044	5.441	.398
"	4	2.213	1.800	.037	.023	.883	6.057	.342
"	5	2.320	3.530	.036	.004	.630	7.599	.074

These steels, experimented on by Messrs. Taylor & White, and showing increased efficiency by the Taylor-White heat treatment, led to the manufacture of high speed Steels. These steels are tool steels, suitable for lathe and planer work. They have been replaced by high speed steels.

Table (22)

HIGH SPEED

"Crucible"

These steels harden in air or oil.

		C.	Mn.	P.	S.	Si.	Mo.	Va.	W.	Cr.
Taylor	1	.682	.07			.049		.32	17.81	5.95
P	2	1.166	.33	.024	.016	.57			15.64	2.69
Taylor	3	1.28	.14			.22			19.97	3.88
"	4	.76	.09			.052	4.21		13.44	3.04
P	5	.861	.11	.021	.014	.072	.	.42	17.21	5.42

These steels followed the self-hardening steels as the result of the Taylor-White discovery. All of these steels harden best in an air blast at 2100° to 2250° Fahr; or in oil; or in a lead bath after previous heating to the high temperature.

HEATING

In general, the lower the carbon is in steel, the higher the heat allowable. ''Dead Soft Basic'' works at a light yellow, while spring steel must not be rolled above a good red. The former will take heavy drafts, at its proper temperature; the latter must be worked down slowly. Between these extremes, in rolling mill, and forge practice, fine gradations are being made by steel workers. Heating is being studied as it has not been heretofore in mill practice, and is given some of the attention that the tool steel workers long ago found so necessary. A fixed draft in a rolling mill demands a fixed temperature in heating; nor will the correct draft remedy a wrong temperature. As in forge practice the hammer man controls the effect of his hammer for various grades and temperatures of steel, so in rolling mill practice it is necessary for the roll designer to regulate the draft of his passes for various grades of steel at the correct temperature. ''Heating'' and ''working'' must be applied to steel scientifically—and ''heating'' so far, has received the less attention.

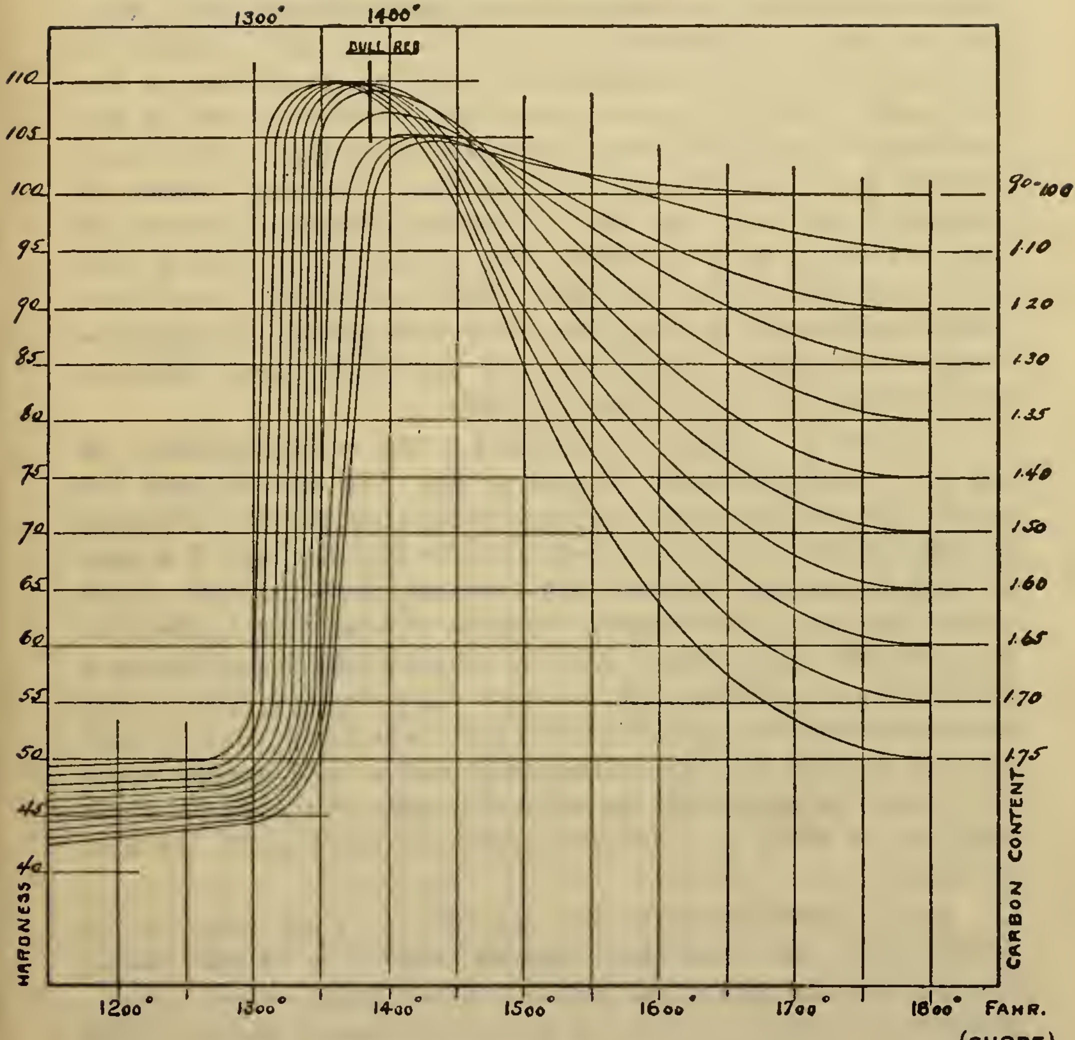
Heating of crucible steels has received more study than has been given to open hearth or bessemer steels. This has been demanded for the reason that high carbon steels are easily ruined and carbon steel was the first product of the crucible. Huntsman made crucible steel by remelting in graphite pots, bars of Swedish iron which had been ''cemented''—i. e., had been heated bright red in closed boxes with alternate layers of charcoal. This was done about the middle of the 18th century and it is a generally accepted fact that crucible steel so made, possesses superiority over all others. In 1801 Mushet patented the process of melting in the crucible with Norway iron bars, ''medicine'' of carbon, etc., saving the time and expense of ''cementing.'' In 1868 R. F. Mushet invented the first of the air hardening steels melting the raw materials in crucibles. Since that time the process has not changed. Various grades of steel and various alloys are made in crucible pots, by either of the two mentioned methods, Huntsman's or Mushet's.

The discovery of the ''Dull Red'' temperature for hardening high carbon steels, and the various temper colors, was made many

years ago. The information is much abused. ''Dull Red'' is not easy to judge; some tool makers don't know it when they see it. In the temper colors some have favorites. It is a fact that every grade of steel has its best working temperature, best hardening temperature, drawing color and cutting speed, and any deviation from these best conditions means a loss to the buyer and user. Steel should be adapted to the purpose at which it is most efficient and the selection of tool steels for various purposes is a man's job. Large users of tool steels carry on experimental work all the time, tabulating brands, prices, cutting angles, hardening temperatures. drawing colors, cutting speeds, wear, waste and outputs; small users would do well to pool their interests for the same purpose—for it is probable that about 3 to 4 times as much tool steel is made and sold as is needed to do the work now required to be done. Two-thirds, or more, is lost; wasted, burned, badly worked—and the price stays up. The first chance of error in treating tools occurs at the heating to work to shape. Carbon steel breaks down very quickly and it pays well to spend plenty of time and care in shaping tools under the hammer. Even in heating to cut off a section be careful to keep carbon steels below a ''red.'' Keep at medium red, and cut slowly.

High speed steels differ from Carbon steels in that they must always be worked at a high temperature, never below bright red. The bad effects of working high speeds at a low temperature equal those of working carbon steels at a high temperature. In their heat treatments, carbon steels and alloy steels (high speeds) are practically opposed to each other.

CARBON CRUCIBLE STEELS



CUT 4

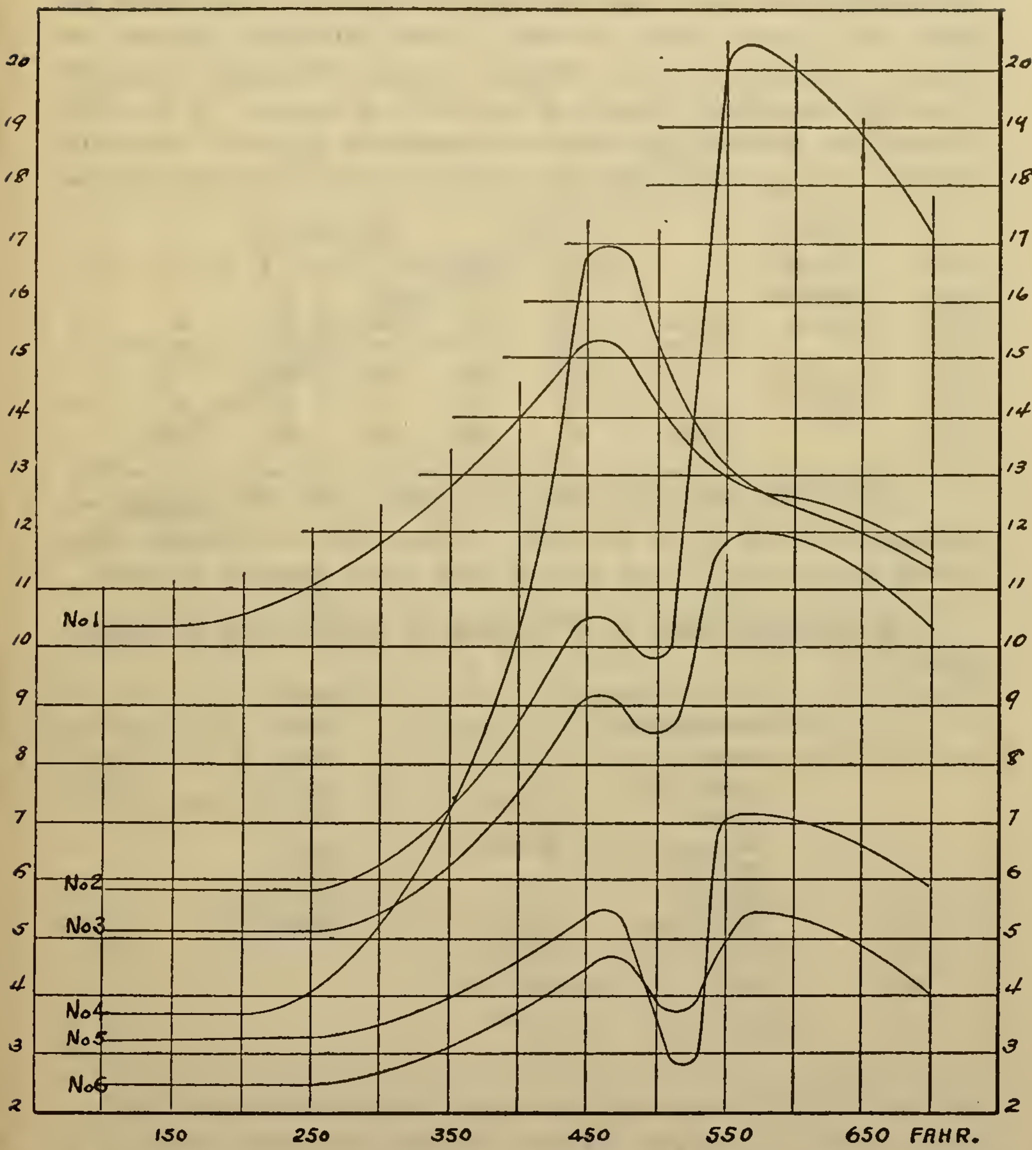
Cut (4) shows the effect of hardening steels of various carbons, at different temperatures. Hardness by the Scleroscope, and relative strengths and losses, are indicated by the figures at the left. The steels were tested to destruction by heating. These curves plainly indicate the effect of over heating to harden; they not only show a decrease in hardness when tested by the Scleroscope, but

indicate the weakness due to crystallization. The higher the carbon, the greater the loss due to any degree of super-heat. Note that the effective temperature for 1.75 carbon steel is limited to a range of less than 15 degrees each side the proper one. A low carbon steel, (.32%), has been heated by the writer to 1800°F. and hardened, without much loss in hardness or strength. This latter was low priced crucible steel intended for "chipping" chisels in foundry work. But this steel, if properly hardened, would not begin to do the work that the 1.75% carbon steel would, if both were properly worked or hardened. High carbon, high priced steel should be hardened at a dull red, never over 1400°F. It should be worked under 1500°, very slowly, with many light blows, with continual reheating as the temperature falls.

Between the ranges of .32% and 1.75% carbon probably lie all the "Carbon" steels in general use. No matter what the carbon, the safe hardening temperature is below 1500°F. If a steel is low in carbon you do not lose much by over-heating; if a steel is high in carbon, .85% or over, you may lose the tool. It is understood that "over-heating" applies to steel that is about to be chilled in water. Steel must be heated to be shaped under a hammer, and a skillful smith, by rapid, light working, will prevent crystallization at a comparatively high temperature. But "bright red" is very hot for high carbon steels, and a rapid hammer is the only means of preserving the original quality of the steel. Work high carbon steels at a dull red, slowly, in shaping, for the best results.

These curves illustrate the necessity of close attention to carbon steels; the more they cost the easier it is to spoil them; but, further, the higher the price of carbon steels, honestly made, and sold, the greater will be the return in service to the user, if he will do his share toward perfecting the process of making tools.

TEMPERING CARBON CRUCIBLE STEELS



CUT 5 (SHORE)

Cut (5) is offered to indicate the care required in tempering, to obtain the desired results. The ordinates are degrees of flexure

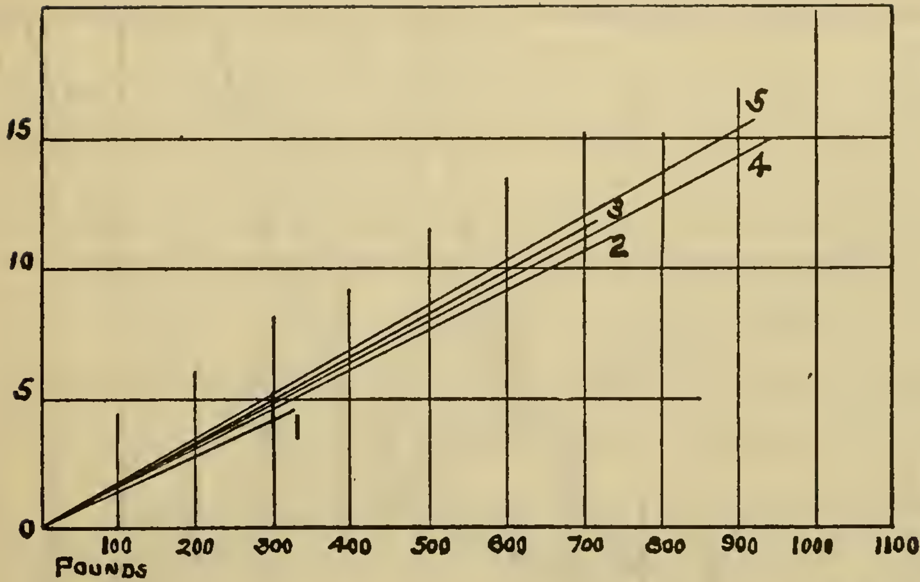
obtained by loading the end of a rigidly held piece of the steel, of standard size, and noting the maximum deflexion from which the piece will recover when released. These ordinates indicate the relative strengths of the different steels, differently tempered. Note the recovery of strength after 535°F. at purple. In the table (below) the hardness at various temperatures is given; this hardness or cutting power, was determined by the Shore Scleroscope.

Curve.	Kind of Steel.		Hardness at 200°F	470°F	520°F	540°F	600°F	670°F
No. 1	Vanadium,		80	72	69	65		
No. 2	Carbon,	1.65%	105	101	98	94	88	
No. 3	"	1.30%	105	100	97	93	86	
No. 4	Vanadium,		92	86	84	79		
No. 5	Carbon,	1.10%	98	95	92	85	83	75
No. 6	"	.90%	91	85	74	73		

As hardness indicates strength, together with the flexure test, the superiority of No. 2, the 1.65% Carbon steel is apparent. Such a steel has no equal for a cutting edge, when properly treated.

The following scale is of interest in determining the temper colors.

Color.	Fahr.
First Color	430°
Straw	450°
Dark Yellow	470°
Brown	495°
Brown, purple flecked........	510°
Purple	535°
Blue	560°
Dark Blue	600°

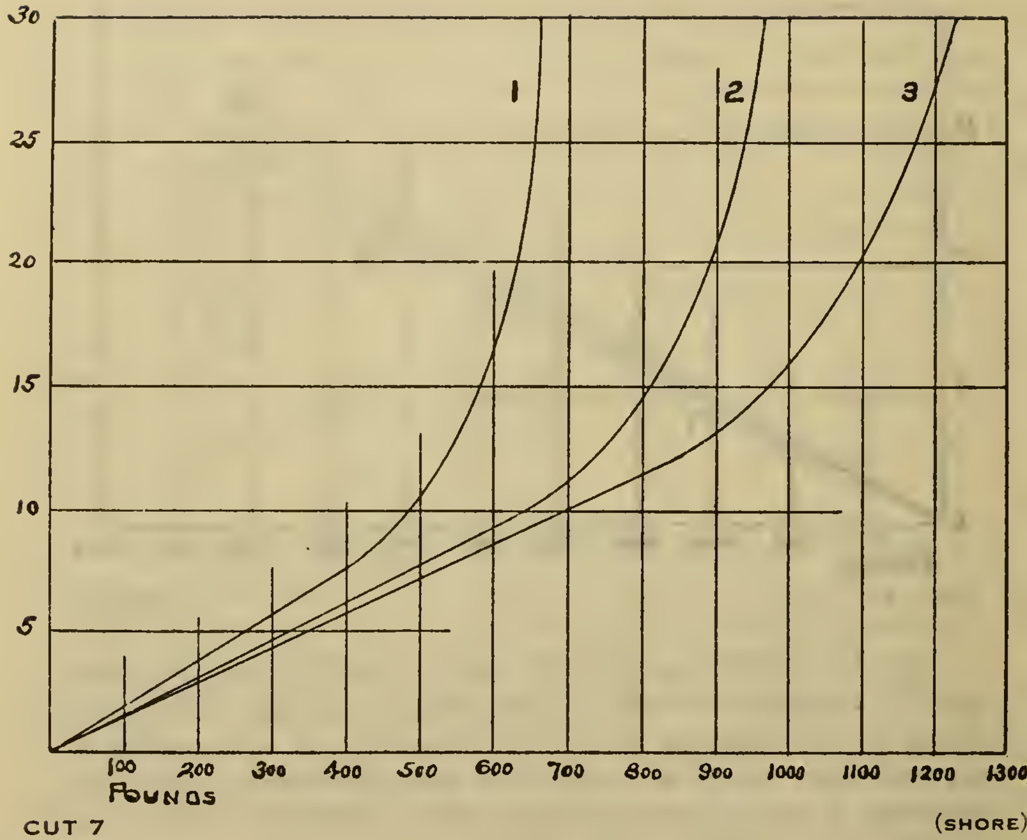


CUT 6

Cut (6) indicates, again, the loss in hardness and the great gain in strength obtained by tempering to various colors. The length of line indicates the limit of elasticity and is a measure of the strength. No. 5 will stand the most punishment; No. 1 untempered is brittle. The following table shows the hardness and cutting power at the various tempers.

Curve.	Kind of Steel.		Color.	Tempered at	Hardness.
No. 1	Carbon,	1.75%	Hardened		110
No. 2	"	"	Yellow	465°F	104
No. 3	"	"	Dark Brown	525°F	98
No. 4	"	"	Dark Blue	600°F	91
No. 5	"	"	....	650°F	88

Such a steel should be tempered to a yellow, 450°F. and used as a cutting tool receiving the minimum amount of shock. Note the hardness at a yellow temper; this is razor steel. Properly handled, its life would easily pay all the cost of manufacture for the most expensive cold die work.

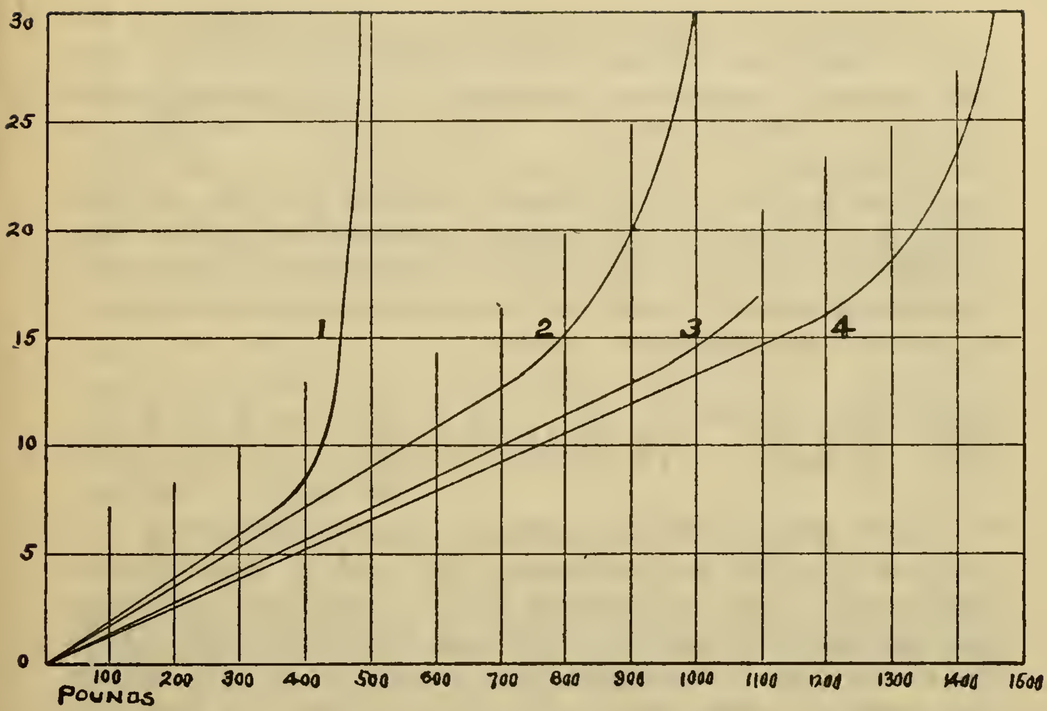


CUT 7

Cut (7) shows a nickel steel, with chromium; a typical chrome-nickel steel.

Curve.	Condition.	Hardness.		
No. 1	Natural	48	Nickel	4.40%
No. 2	Tempered 535°F	62	Chromium	1.53
No. 3	Hardened	75	Carbon	.26

Hardness is sacrificed for a slight increase of ductility by tempering. Chrome-nickel steels possess great toughness, but do not have extreme hardness. They may be used to advantage without temper drawing, as curve No. 3 indicates; they show great resistance to repeated or dynamic shocks, whether "natural," "hardened" or "tempered."



CUT 8 (SHORE)

Cut (8) shows the effect of tempering a vanadium steel, for axles, to various colors.

Curve.	Tempered, F°	Hardness.
No. 1	Natural bar	46
No. 2	600	79
No. 3	520	84
No. 4	470	86
	Hardened	92

The remarkable strength indicated by curve (4) is typical of vanadium steels, well made. It requires careful handling.

All of these curves show the need of care in handling high priced steels. Steel is spoiled in the heating process more easily than by any other treatment. Conditions and appliances which regulate the treatment and perform the work, are absolutely necessary. "Guessing," too much "experience," are not heat regulators.

In ordering crucible steels that are to be machined to size before being heat-treated, always specify sizes that will allow the removal of the outer skin and scale. This is absolutely necessary, both in carbon steels and in high speed alloys. The following scale is suggested. The allowances are liberal, but it is intended to avoid bad products at the comparatively small expense of additional steel and the cutting to shape. Annealed bars generally lose in hardness and bars of all shapes are generally less hard on the exterior than below the skin, after being heat-treated in the natural, or rolled or hammered size.

Nominal Sizes (inches)..	1	1½	2	2½	3	3½	4	4½	5	6	7
Specify for Rounds.....	1 1/16	1 9/16	2⅛	2⅝	3 3/16	3 13/16	4¼	4¾	5⅜	6 7/16	7½
Specify for Squares....	1⅛	1⅝	2 3/16	2 11/16	3¼	3¾	4 5/16	4⅞	5½	6 9/16	7⅝

In the long run it pays to state the use to which steel is to be put and to let the maker determine the grade or size, as in the above table. Tool steel makers receive complaints from users; the user hears the complaint of his own tool maker. The chances for advancement in knowledge, from experience, lie with the man that makes the stuff. Some steel plants are over 100 years old; their letter files would probably make a valuable text-book of tool steel specifications.

HIGH SPEED STEELS

The treatment of "Self-hardening" steel is not offered. It may be stated that any alloy steel requires careful treatment, especially those in which chromium, vanadium, or tungsten are used to increase the strength due to carbon. When a "Self- hardening" steel carries sufficient Tungsten and Chromium to advance it into the "High Speed" grade, it becomes a member of that grade, as the Taylor-White discovery showed.

HARDENING HIGH SPEED STEELS

These directions are intended to be explicit; each item is important.

(1) Cut tool lengths from the hot bar—at red (1700°F.) or higher. Do not cut bars cold by nicking and breaking. Annealed bars may be cut by power-saw or in a lathe, but at a slow speed.

(2) Heat the steel in a clean fire, without blast, until the piece is thoroughly heated; increase the blast until the steel becomes very bright red, nearly yellow. Commence to forge; when the temperature falls below a medium (1700°) red, reheat as before. Do not work this steel below a medium red, and preferably not below a bright red.

(3) When the tool is rough forged, cool slowly in a dry place.

(4) For convenience, grind the forged tool to the approximate shape desired, but not to the finished shape, on a dry stone. This is optional; stock must always be left at the cutting edge, (1-16" to 3-16") to allow for hardening.

(5) Having followed 3 (or 4), to harden, heat slowly in a clean fire to a **Bright Red**, then more rapidly to a **White Heat, dazzling white**; withdraw from the fire and cool in a strong cold, dry, air blast. (Rape, whale, or cotton seed oils may be used for cooling, but air is the best).

(6) Grind the tool carefully, by hand, on a wet sandstone or emery. Use care in grinding or the steel will heat to the annealing temperature and lose its cutting power.

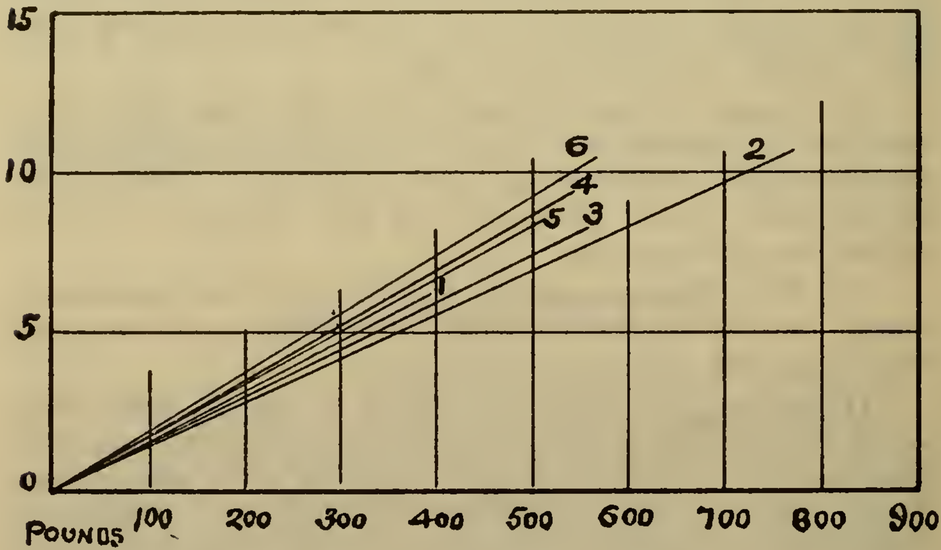
The foregoing directions are complete for all high speed steels and if followed will give the best results that any steel will give, regardless of its brand, if it be a true high speed steel. Leave plenty of stock at the cutting edge; if the extreme edge begins to ''run'' when being heated to harden, and the whole nose of the tool is thoroughly and strongly heated, the hardening effect will be at its maximum. The tool should be hot from lip to heel, and back to the shank. A coke fire for hardening is the best; there should be plenty of fuel on the tuyere and a good strong heat.

Mr. Taylor recommends a second or low heat treatment for high speed steels, substantially as follows:

(1) Reheat the already hardened tool slowly, preferably in a coke fire, not to exceed 1200°F. and place in a lead bath of at least 3600 pounds weight, which is rigidly maintained at a temperature of 1150°F.

(2) Allow the tool to remain in the lead bath not more than 5 minutes, remove and cool in the air blast, as before. Care must be taken that the temperature of the previously hardened tool does not go above 1240°F., the breaking down, or annealing temperature.

If a tool is accidentally so heated in the process of manufacture, it should be heated as stated above, for hardening, worked lightly with hammer, cooled slowly, and again brought to the hardening heat (2200°F.). The object of the second low heat treatment appears to be the removal of internal stresses and to make the hardening effect more uniform.



CUT 9

Cut (9) indicates the hardness, elastic limits and strengths of a sample of high speed steel heated to various temperatures, hardened by different means, and in two cases "tempered."

Curve.	Hardened at	Hardened in	"Tempered."	Hardness.
No. 1	2250°F	Oil		99
No. 2	Rolling Heat	Air		101
No. 3	2150°F	Oil	650°F	95
No. 4	2000°F	Air	650°F	94
No. 5	2150°F	Air		99
No. 6	2100°F	Air		90

Generally, high speed steels are not tempered. The reheating to 650°F. above a blue, indicates a temperature at which this particular brand held its hardness or cutting power. This grade of steel, if held at this temperature, and cooled very slowly would show exceptional resistance to dynamic shock and would prove very valuable for such purposes. Note the loss when hardening at lower temperatures. "Tempering" having been carried further as in the low heat treatment, Taylor-White process, up to 1150° and then cooled in air, a return of hardness would probably have taken place. This steel is about as hard as the usual 1.20% carbon steel hardened at 1400°F. It is very much stronger than the carbon steel, will stand shocks better and is in general the superior tool for cutting purposes. A very high carbon steel, however, takes precedence for slightly smoother cutting edges, greater hardness and sufficient strength for the purpose where it is not shattered by heavy work. High speed will cut at a temperature of 1000°F. and over where carbon tempered steels are useless.

COMPARISON.

The very best carbon steel made today is worth 40 cents per pound; this steel is unequalled, but it requires experience, skill and absolute adherence to the laws for shaping, finishing, hardening and tempering. The best high speed steel sells for $1.20 per pound. As cutting tools, those two steels are hard to compare. The high speed will not take the edge that can be given the carbon steel; it will not take the smooth finish, is not so suitable for fine cold die work, for which the carbon steel is excellent, nor will it cut chilled rolls so smoothly. But if tools of these two steels are shaped, and heat-treated, each to its best, for lathe work, the high speed steel would give 10 times the yield. Further it would cost less to work into a tool, both bars being the same size,

since the high speed steel is worked at a high forging heat. For a "glass finish," for hardness when cold, a keen edge, and smoothness the carbon steel is the better, and is in fact unsurpassed. For ease of hot working, cutting power at high speeds and temperatures, resistance to shock, toughness, wearing power, ability to recover when over-heated (by reheating) the high speed steel is 4 to 10 times better than any carbon steel.

Carbon steels range in price from 5 cents per pound to 40 cents per pound. "High Speeds" from 55 cents to $1.25. For lathe, planer and boring mill roughing tools, for cutting in fact, the 55 cent steel is 4 to 8 times as effective as the very best carbon steel. There is no comparison between the two steels for this purpose.

Very slowly the high speed steels are replacing the carbon steels for dies, especially in "hot" work, for bolts and rivets. The user should bear in mind the fact however, that high speed steels do not harden to the degree that carbon steels do. If the die must be very hard, carbon steel is the thing; if it must be only relatively hard, must hold its hardness when hot, say 1000°F. and must above all be strong, high speed alloys are the best. The table on page 35 shows the hardness of High Speed steels; soft steel on the same scale is about 35 hard, while the best carbon steels will show 110, when hardened.

All grades of steel have been tried both in carbon and high speeds for hundreds of purposes. The very best shops continue and will continue to try and there are three very good reasons:

(1) The trials made for some reason or other are incorrect and not authoritative; for want of time, or because of material, or error, or exact comparative data.

(2) Steel continues to improve in quality; the demands on it continue to increase; the user's knowledge grows, as witness the employment of steel experts.

(3) The progressive man is always trying according to his judgment.

HIGH SPEED STEELS

The manufacture of High Speed steels entails all the expense of carbon steels with the additions of the cost of the raw materials and the skill in balancing the alloys so that hardness or cutting ability may be obtained and retained at a high temperature. Tungsten is expensive, as are chromium and vanadium. Unless the product is correct in analyses the whole melt is lost; in the carbon steels an incorrect analyses for one grade may be a correct one for another. High speed steel makers have two or three brands on which to apply their steels; carbon steel makers have a dozen.

While high speed alloys are mainly used at present for roughing tools, and for dies, etc., in hot work, there is nothing to prevent their use for finer tools. There is a tendency to believe that high speed steels are not effective unless heated to a temperature that destroys the shape of cutters, drills, etc. This is not true. It is a fact, however, that when heated to 2200°F. they are hardest; it is also a fact that they are exceedingly hard when cooled from a lower temperature, and they are very strong. If then, a tool made of a high grade alloy be hardened in oil from a temperature of 1900° there will result a cutter that will stand up under heavy work, that will give an increased yield, especially if run with water, and will be capable of cutting much faster than a carbon tool. As stated before, for very keen edges with absence of shocks, and for hardness, together with price, the carbon steel is preferable; for heavy work of all kinds, for speed, rough handling under severe conditions, long life, certainty of yield of labor applied to it, the higher priced, well made alloy is the best. It is the more efficient product.

THE RANGE IN CUTTING SPEEDS

This table is made up of data taken from F. W. Taylor's book "On the Art of Cutting Metals" and aims to show the possibilities of high speed steels as well as the existing facts. The tables and numbers referred to are those on pages 19 to 22, the figures, feet per minute.

Table (23)

Table.	No.	Medium Forgings.	Hard Forgings.	Cast Hard Iron.	Soft Cast Iron.	Kind of Steel.
18	3				47′	Carbon, tempered
18	6	16⅔′			48′	" "
18	7	16′	6′		47½′	" "
18	9	16′	6′		47′	" "
19	1	18′	7′		71′	Carbon, chrome
21	1	25⅔′	12′		89′	Self hardening
21	3	25′	7¾′		86′	" "
22	3	84′	38′			High speed
22	4		37′	45½′		" "
22	1	99′	41½′	52′		" "

The following ratios of cutting efficiencies developed since 1906, as shown by practical experiment and shop work, are of interest.

Relative values of High Speed Steel over	Medium Steel.	Hard Steel.	Hard Cast Iron.	Soft Cast Iron.
Carbon (tempered)	6 to 7	7 to 8	3 to 4	3 to 4
Carbon Chrome (tempered)	5½	6	3 to 4	3 to 4
Self Hardening	3 to 4	5	2	2 to 3

Or, assuming high speed steel 100% efficient, self-hardening steel is 30% efficient; carbon chrome-tungsten is 20% efficient; carbon steel 15% efficient.

The analyses of "medium" and "hard" steel and "hard" and "soft" cast iron are important, and Mr. Taylor's classifications are given below, as used by him.

	Medium Steel Forgings.	Hard Steel Forgings.	
Carbon	.34	1.00	
Manganese	.54	1.11	
Silicon	1.76	.305	
Phosphorus	.037	.036	
Sulphur	.026	.049	
Tensile strength	70280	91670-101860	(each end)
Elastic limit	34630	60090-53980	" "
Percent of extension	29	7-5	" "
Percent of contraction	44.34	11.66-9.73	" "

Hard Cast Iron.

Carbon, Total	3.32
Combined Carbon	1.12
Manganese	.68
Silicon	.86
Phosphorus	.78
Sulphur	.073

"Medium" and "hard" steel forgings are shown in tables (12) and (13) of this book.

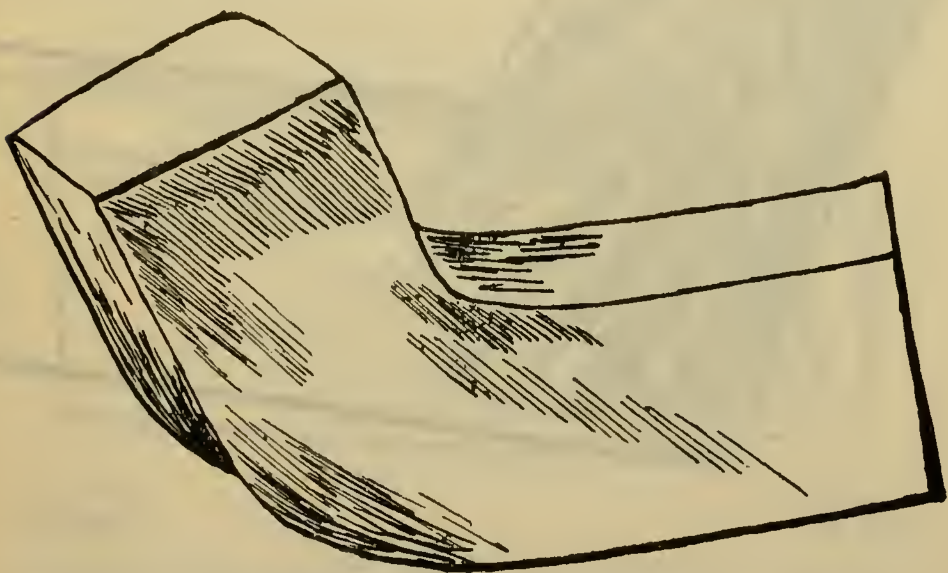
The following speeds, based on observation, may be expected with the best modern high speed steels that have been properly worked and heated.

Table (24)

Material.	Depth.	Feed	Speed, Ft. Per Min.
Soft Cast Iron.............	1/4	1/8	100 to 150
" " "	1/4	1/16	125 to 175
Soft Steel Forging..........	1/4	1/8	100 to 150
" " "	1/4	1/16	125 to 200
Medium" "	1/4	1/16	80 to 125
Hard " "	3/16	1/16	80 to 100
" " "	1/4	1/16	70 to 90
" " "	1/4	1/8	50 to 80
Very Hard "	1/4	1/16	40 to 60
" " "	1/4	1/8	30 to 50
Hard Cast Iron	3/16	1/16	40 to 60
Wheel Tires	1/8	1/8	20 to 30
Manganese Steel	1/8	1/16	8 to 20

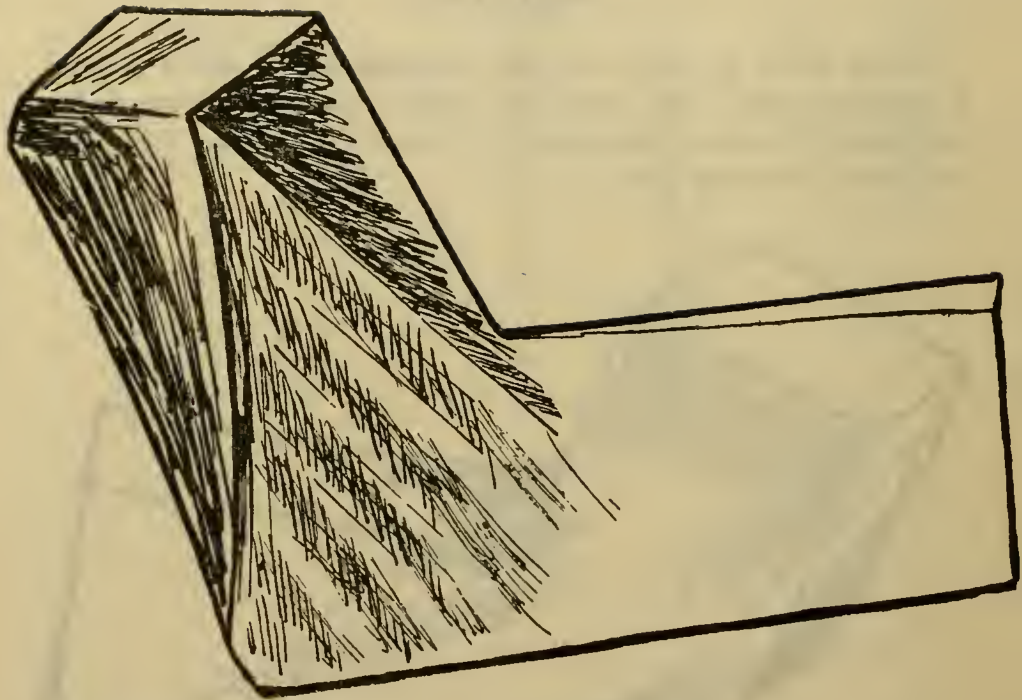
SHAPING

Cuts 10 to 15, show the best, simplest and cheapest forging methods for solid tools. As much work as possible is done under the hammer to save dangerous and expensive grinding. These are high speed roughing tools.



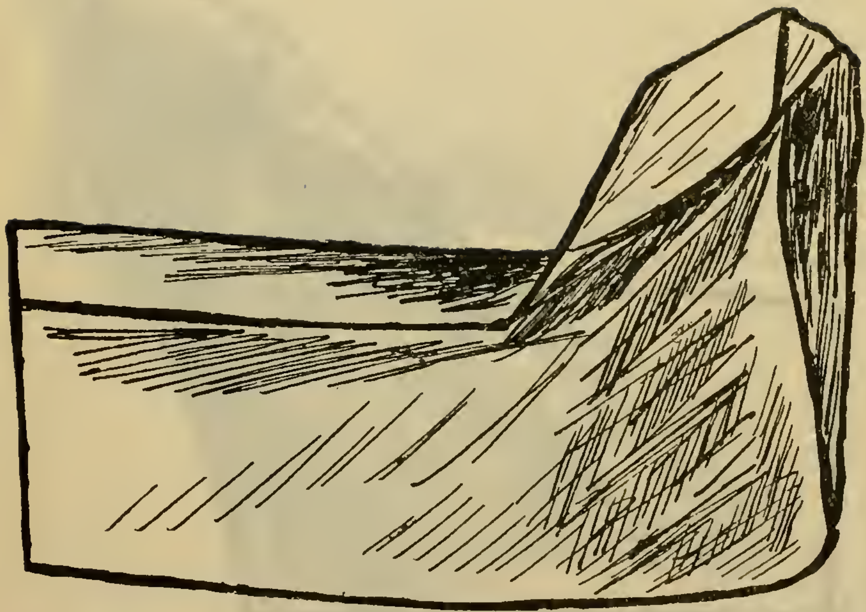
CUT 10 (TAYLOR)

Heat to bright red and turn up on anvil to about 80 degrees.



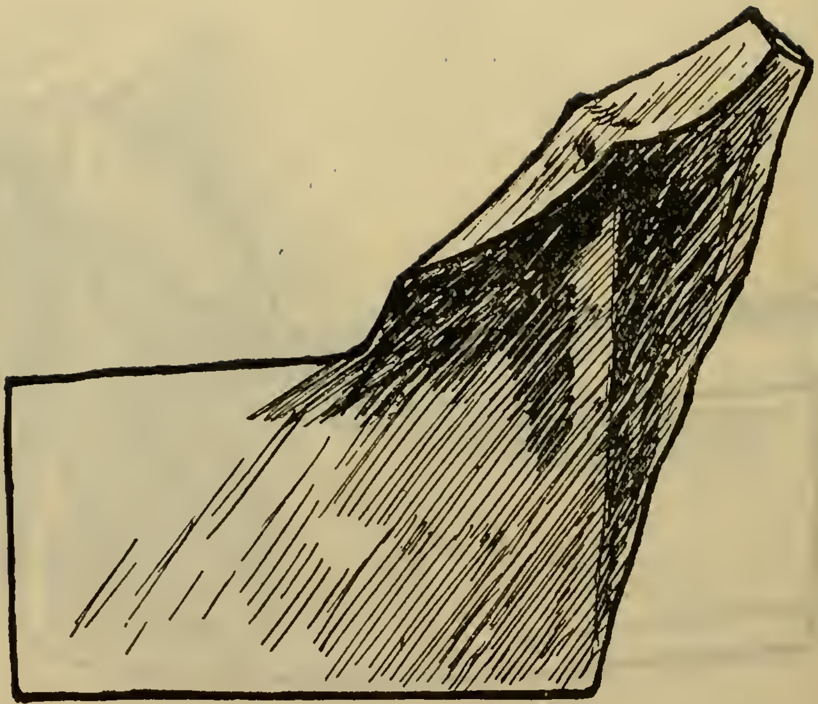
CUT 11 (TAYLOR)

Draw down strongly at the heel, using a light steam hammer. Trim level on bottom. Trim on front to maintain angle of about 80°.



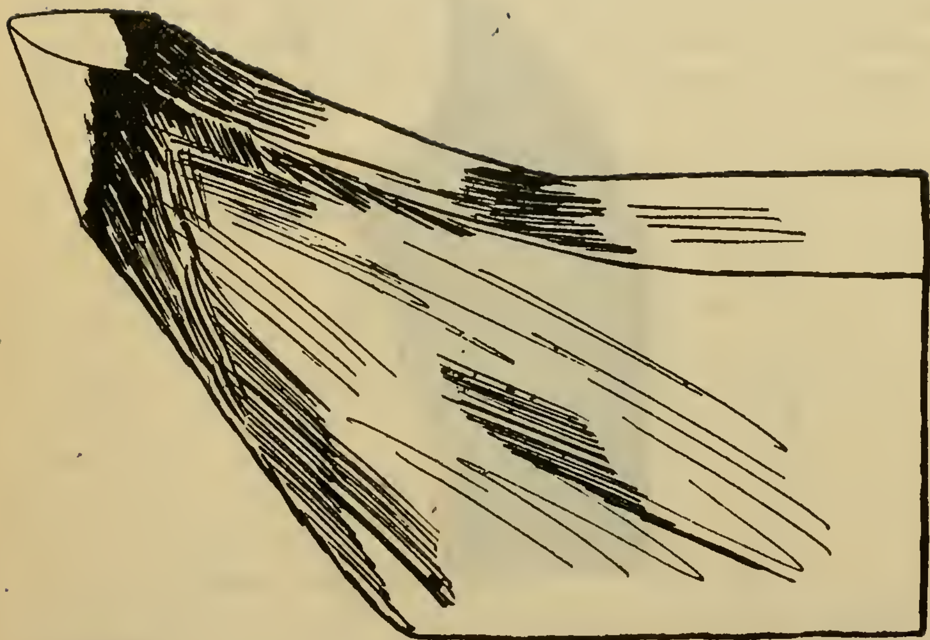
CUT 12 (TAYLOR)

Trim top, at nose, for back and side slopes.



CUT 13 (TAYLOR)

Trim for clearance. Round into shape, smooth up; use a cone gauge. Rough grind at this point, and heat to high temperature for hardening, about 2200°F. At this point a dry stone may be used in grinding.



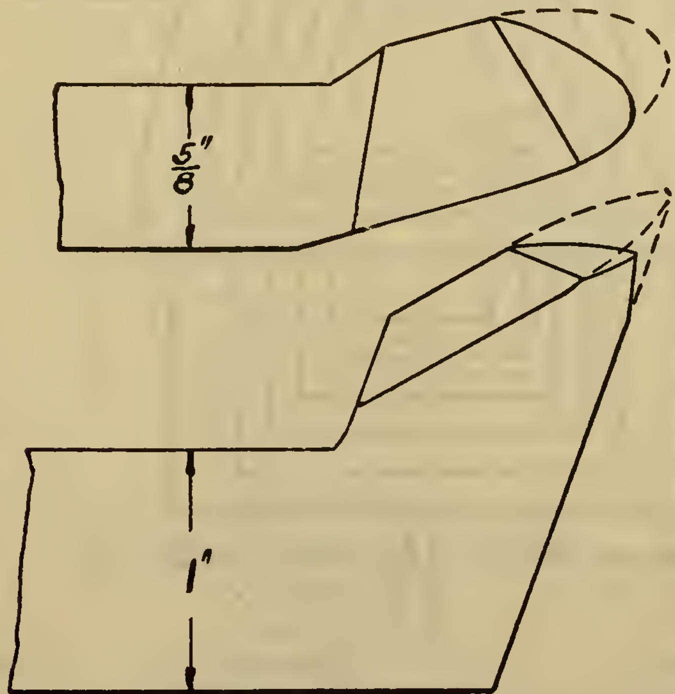
CUT 14 (TAYLOR)

Grind to shape desired on wet stone, with proper clearance, back slope and side slope at the cutting edge.

CUT 15 (TAYLOR)

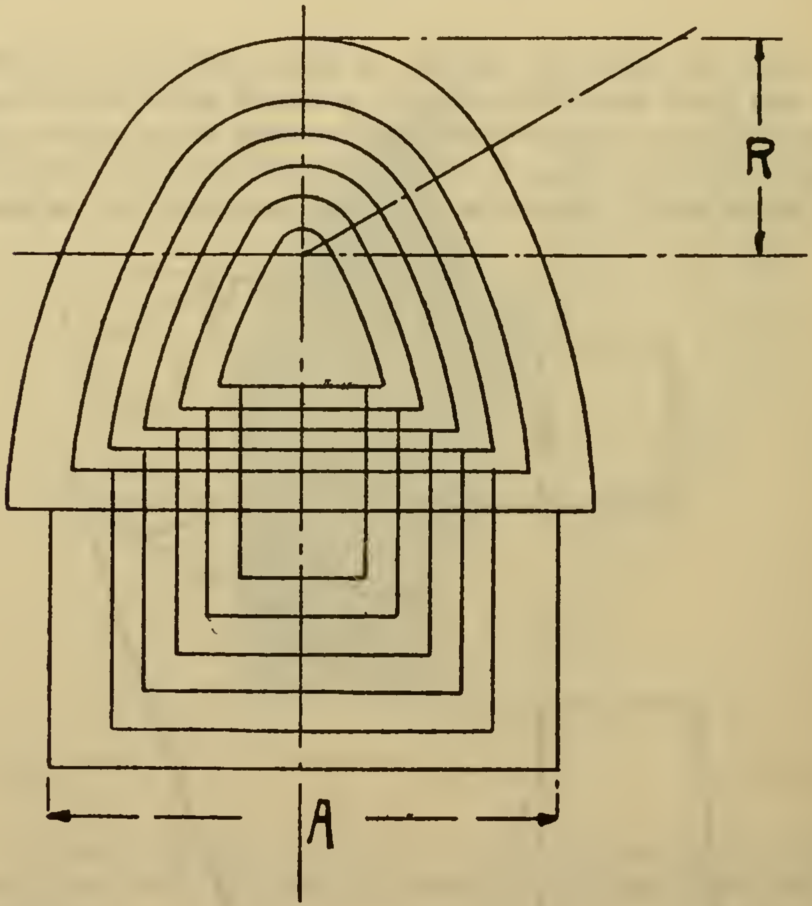
The tool, finished, from the front. In forging reheat as many times as necessary, keeping the temperature always above medium to bright red.

Cut (16) shows the manner in which extra stock is left at the tool point, not only to afford a means of noting the hardening heat, but to give metal for grinding to arrive at the proper cutting angles. For hardening, if the dotted point begins to "run" and the whole nose of the tool is hot, the temperature is at its best.



CUT 16 (TAYLOR)

Cuts 17 and 18 show the best radii for cutting edges for round nose roughing tools. These tools will take the maximum cut and feeds with the least amount of pressure and the least "chattering."



CUT 17 (TAYLOR)

BLUNT TOOL

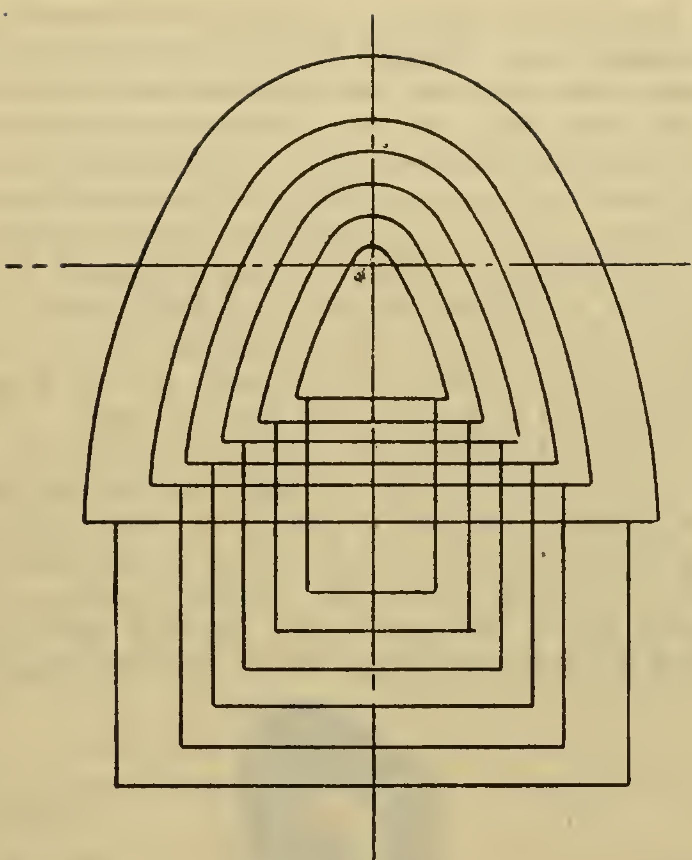
For Cutting Hard Steel and Cast Iron.

Clearance 6°

Backslope 8°

Sideslope 14°

Radius of Point $= \frac{1}{2}A - \frac{5}{32}$



CUT 18 (TAYLOR)

SHARP TOOL

For Cutting Medium and Soft Steel.

Clearance 6°
Backslope 8°
Sideslope 22°
Radius of Point $= \frac{1}{2} A - \frac{3}{16}$

The best shape of stock for stiff tools is that in which the depth is 1½ times the width, or for a 1″ tool we have a bar 1½″x1″. There are exceptions in boring mill tools where squares and rounds are used to advantage. In boring mill tools, care should be taken to maintain the proper angles.

Cut (19) serves to indicate a means of obtaining a cutting edge for special tools. The face of the tool is hollow ground on a small stone. The machinist who uses this method claims good results. He rough forges the "cup" during the shaping up with a ball and has little grinding to do. It is a very simple and effective means of obtaining the proper angles, a circular template of the proper diameter giving the correct slopes for any given width of face. Such a method is excellent for small standard tools of expensive carbon or alloyed steels having a fixed amount of cutting to do on the casting to which they are applied. Planer and shaper tools, finishing out recesses, bearing seats, etc. to size, can be shaped and finished in this way with excellent results. The use of a cupping ball by the blacksmith will carry out this idea in many tools. The cut shows a "hollow ground" cutter of the usual type. This is a principle that may be applied to other cutting tools to advantage. One of the advantages claimed is the breaking of the chip, due to the action of the "cup" or concave face. A roughing tool, cupped out in this manner will travel in either direction; this method is not recommended, however, for heavy roughing work.

CUT 19 (TAYLOR)

In general, the better man will develop more returns from the cheaper priced steels than will his competitor; but the better maker of tools of all kinds will buy the highest priced steel that his average of accidents will permit. In a word, he saves time by using more expensive steels than his competitor, when he knows how to handle them better.

Usually the labor of shaping the steel exceeds the cost of the material. In the case of dies the labor cost may be easily 400 to 500 times the cost of the steel. Relatively, the steel cost in such a case is of no importance. Another factor always enters here however; mainly, the ability to work the high-priced steel without injuring it. It is easy to show in hundreds of shops by handing a blacksmith two pieces of carbon steel shaped alike, one worth 4 cents and one worth 40 cents a pound, that the 4 cent steel is the one to use, in that shop. The 40 cent steel fails because it gets a 4 cent treatment—and the trouble all comes in the heating. In the high speeds, in the same way, the 50 cent alloy wins out over the $1.00 alloy; but here the trouble comes from working at a low temperature, below 1500°, or not heating hot enough to harden, or grinding on a dry stone and annealing the point at 1240°. It is a fact that reputable makers grade steel to a nicety; it's up to the mechanic to take advantage of what the steel maker knows about heat treatment.

A good sensible way to look at tool steel is from a basis of relative cost—material to labor. If we have,

Steel at	$ 4.00
Labor at	400.00
Cost of die	$404.00

We can afford to pay

Steel	$ 8.00
Labor	400.00
Cost of die	$408.00

increasing the cost, by less than 1% and, in many cases, doubling the yield—provided

we do not injure the $8.00 steel. If, however, the $4.00 steel will make what we have to make, and becomes scrap afterwards, it is the steel to use.

Grading steel is a science in itself. The group of men with the greatest knowledge in this regard are the steel makers. Each user is one factor on the opposite side, studying his own problem, taking advantage of his own experience, but rarely getting accurate knowledge of his competitor's methods, or of any other methods. This booklet aims to show the need of co-operation probably through the press, with the best information coming from the manufacturer. It indicates the precision, the care, the thought, that goes into specifications and the treatment of steel, and aims to help the user to take care of the most serviceable metal we have, rather than to waste it.

TO HANDLE TOOL STEELS

1. Never nick and break cold bars.
2. Work high speeds at a yellow, never below red.
3. Harden high speeds at a white heat.
4. Never heat a carbon steel above bright red, no matter how little it costs; never heat a 40 cent carbon steel above medium red.
5. Water on the point when cutting increases the power of high speed tools by 20%.
6. Water on a red hot high speed steel may ruin it.
7. Heating high speed steel above 1240°, as in dry grinding, destroys its cutting power; it is necessary to go through the hardening process again.
8. Air is best for hardening high speeds; use oil when hardening for taps, drills, dies, etc., at a lower temperature.
9. Be careful in using a bath; too long exposure, or too high temperature by a very small margin, makes you reharden.
10. For roughing tools, the cutting angles given in this book are probably the best. It takes care to keep them always the same; but it pays to be careful.
11. Select your steel; keep a record.
12. Grind wet, to finish; grind dry (high speeds) before you harden,
13. Any good high speed will deliver red-hot chips; but you will generally find that the tool that does so in trial was ground by the salesman. He merely gets the best out of his product. Do you?
14. Don't grind a high speed twist drill on a rough dry stone, just because it is a wonderfully strong tool. The steel in some of these drills cost $1.25 per pound.
15. Make a gauge of two pieces of No. 10 sheets, slotted, with a thumb screw to hold them. Let the vertical piece slope on one edge to 6° clearance, and mark off back and side slopes with a scratch. You can grind correctly with such a gauge.

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